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Elevational range extension of the marsupial frog, *Gastrotheca marsupiata* (Duméril & Bibron, 1841) (Anura, Hemiphractidae), from southern Peru

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Abstract

We extend by 300 m the known upper elevational range of the Marsupial frog, *Gastrotheca marsupiata* (Dumeril & Bibron, 1841), to 4,660 m a.s.l. This record makes *G. marsupiata* the highest occurring frog in its genus, which is already characterized by high-elevation distributions. We suggest that this record may represent a case of climate-induced range shifting and discuss this record in the context of our still limited understanding of how amphibian distributions are being affected by climate change.

Keywords

Amphibian, Andes, Cusco, *Gastrotheca*, Vilcanota mountains

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Introduction

The genus *Gastrotheca* (Fitzinger, 1843), known as marsupial frogs, comprises 75 formally described species (Amphibiaweb 2020; Frost 2020). Although some *Gastrotheca* occur in Central America and eastern South America, their diversity peaks in the Andes (Frost 2020). *Gastrotheca marsupiata* (Duméril & Bibron, 1841), the type species of *Gastrotheca*, is distributed along the Cordillera of the Andes within the Amazonian drainage

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systems (Frost 2020). Its type locality is in the Peruvian department of Cusco (Guibé 1950) and its range is one of the largest in the genus, stretching from central Peru to southern Bolivia (Duellman and Trueb 2015; Frost 2020; IUCN 2020). *Gastrotheca marsupiata* occurs in montane cloud forests and treeless, puna habitat characterized by bunchgrasses (Duellman and Trueb 2015) and can persist despite agricultural conversion and forest degradation (IUCN 2020).

Like other marsupial frog species, female *G. marsupiata* have a dorsal pouch where the male places the eggs following fertilization (Dumeril and Bibron 1841; Duellman and Trueb 2015). Fertilization and transfer usually happen away from water, and the eggs hatch in the pouch (Del Pino 1989). In some *Gastrotheca* species, the tadpoles remain in the pouch until metamorphosis, but *G. marsupiata* deposit their tadpoles into stagnant or slow-flowing water to live as free-swimming tadpoles prior to metamorphosis (Duellman and Maness 1980; Sinsch and Joermann 1989). Observations of this and closely related species suggest that the tadpoles remain in the free-swimming stage between 1.5 months (Hoogmoed 1967) and nearly a year (Del Pino and Escobar 1981). Therefore, stable water resources are an important habitat requirement for this species.

Gastrotheca marsupiata, reported as ranging between 2,500 and 4,360 m a.s.l. (IUCN 2020), is one of only seven *Gastrotheca* species ranging above 4,000 m a.s.l., along with *G. dissimilis* (Vellard, 1957), *G. excubitor* (Duellman & Fritts, 1972), *G. pacchamama* (Duellman, 1987), *G. pseustes* (Duellman & Hillis, 1987), *G. griswoldi* (Shreve, 1941), and *G. peruana* (Boulenger, 1900) (Duellman 2013; Duellman and Trueb 2015; Vargas 2015; Frost 2020; IUCN 2020). Of those, only *G. peruana* and *G. pacchamama* have been recorded up to 4,600 m a.s.l., making them the highest-elevation members of the genus until the present record. Here, we report a 300-m elevational range extension for *G. marsupiata* into Osjollo Pass in the core of the Cordillera Vilcanota. This brings *G. marsupiata* to a maximal elevation of 4,660 m a.s.l. and makes it the highest-occurring species in a genus already characterized by high elevation ranges.

The Cordillera Vilcanota, which extends approximately 80 km east–west and 40 km north–south across part of the departments of Cusco and Puno, has the largest Peruvian glacier and the second-highest density of glaciers in Peru (Morales-Arnao and Hastenrath 1999). As Osjollo Pass deglaciated following the Little Ice Age maximum (ca. 1850–1900), three anurans expanded their elevational range into this newly ice-free habitat: *Telmatobius marmoratus* (Duméril & Bibron, 1841), *Pleurodema marmoratum* (Duméril & Bibron, 1840), and *Rhinella spinulosa* (Wiegmann, 1834). The former two species, in so doing, have become the highest-living amphibian species worldwide (Seimon et al. 2007). *Gastrotheca marsupiata* is sympatric with these other three amphibians lower in their range, and may similarly be expanding upslope with the shifting climatic conditions.

Methods

On 21 March 2018, our team found tadpoles and metamorphosing froglets in a small pond on the northern side of Osjollo Pass in the Cordillera Vilcanota, Peru (Fig. 1). The tadpoles and froglets were identified as *Gastrotheca marsupiata*, as other regionally occurring *Gastrotheca* species deposit froglets rather than tadpoles from their pouches (Duellman and Fritts 1972) and have a lower maximum elevational range than *G. marsupiata* (IUCN 2020). One froglet was photographed with a Nikon D7200 and Tokina 100mm macro lens to later confirm field species identification using the descriptions of Duellman and Fritts (1972) (Fig. 2), though no voucher was taken.

On 8 May 2019, the field team returned to search for an adult individual by diurnal rock flipping. One specimen was collected, photographed as previously, euthanized by an anesthetic overdose of 20% benzocaine hydrochloride gel applied topically to the ventrum, and preserved in 70% ethanol. The species was identified using the descriptions of Duellman and Fritts (1972). The voucher specimen was deposited at the Museo de Biodiversidad del Perú (MUBI), Cusco, Peru.

Coordinates were taken using a handheld Garmin GPSMAP 64s. The datum used for recording geographical coordinates was WGS84. Collections were made under a permit issued by SERFOR (no. AUTIFS-2019-014) and an animal care and use protocol approved by University of California, Berkeley's ACUC (no. AUP-2018-12-11648).

Results

***Gastrotheca marsupiata* (Duméril & Bibron, 1841)**
Figure 2

New record. PERU • 1 subadult ♂; Cusco Department, Quispicanchis Province, Cordillera Vilcanota; 13° 70.00′S, 071°13.87′W; 4,660 m a.s.l.; 8 May 2019; E. Steigerwald, Y. J. Guevara, and G. Crispin leg.; under a stone in moraine that was thinly colonized by grasses, ca. 5m from a stream; MUBI 16429.

Identification. Identification was made using information about the geographic distribution of *Gastrotheca* species as well as key traits. The observation of free-swimming tadpoles and metamorphosing froglets differentiates this species from other *Gastrotheca* species in the region, which carry their young past the tadpole stage (Duellman and Fritts 1972). Additionally, other *Gastrotheca* species in the region are found at lower elevations, well below the elevational limit of *G. marsupiata* (IUCN 2020). Further identifying characteristics of the adult frogs were the acutely rounded snout, round canthus, dark canthal and postorbital striping on the head, lighter labial stripe, pronounced supratympanic fold over a vertically ovoid tympanum, smooth tympanic annulus, and slightly concave loreal region. Diagnostic features

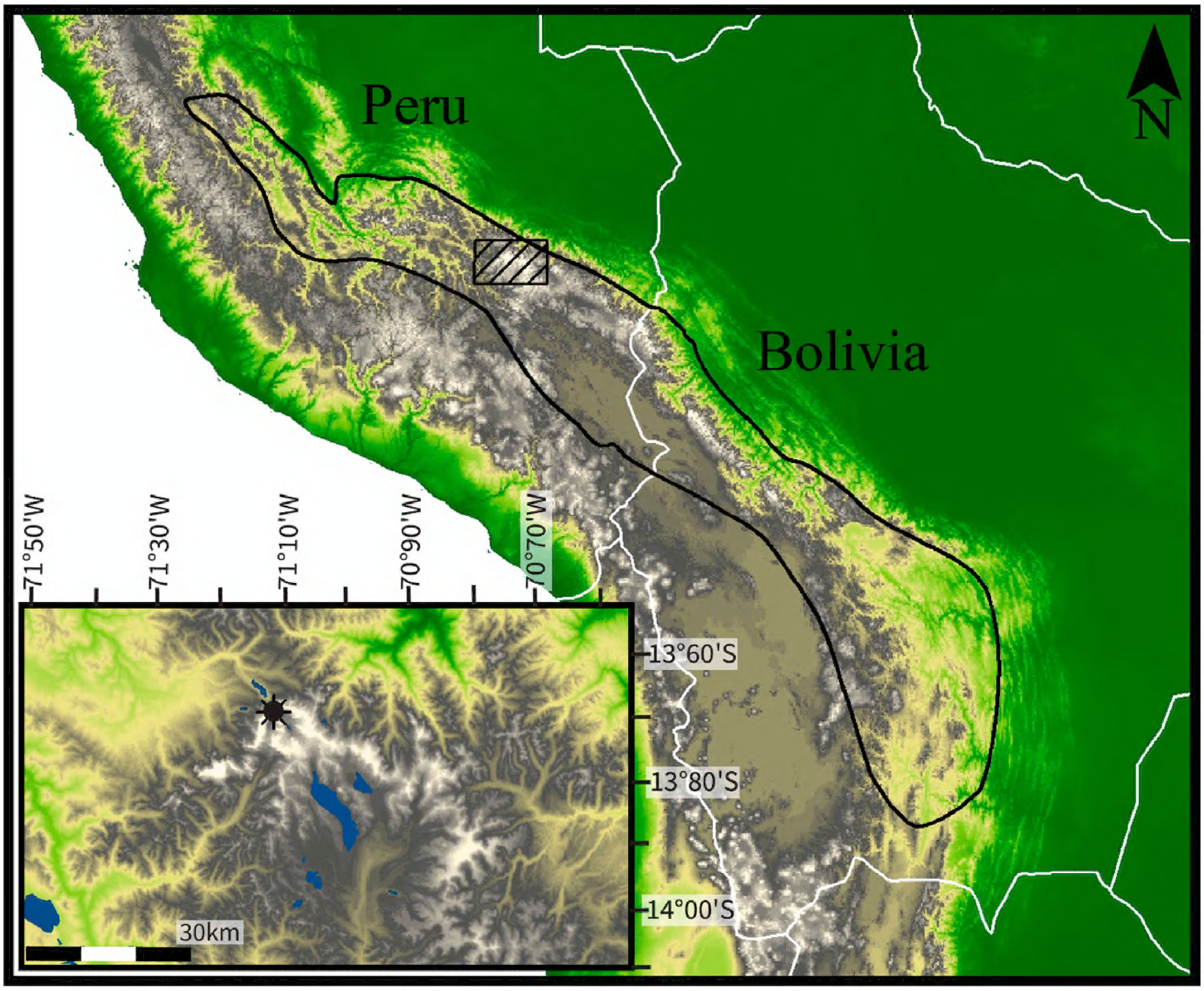

Figure 1. Distribution map of *Gastrotheca marsupiata*. The white lines represent national borders, and the black outline represents the species distribution (IUCN 2020). The small, hatched box marks the location of the inset map, and the black star on the inset map represents the location of our new record.

observed on the limbs were the lack of webbing between the fingers on the hands, toe pads that are slightly wider than they are long, and pronounced large round subarticular tubercles on the hands. A slightly granular dorsal skin with dark green markings on the dorsal side, transverse bars or spots on the dorsal portion of limbs, and mottling on the lateral portions of the body all confirm that individuals observed were *G. marsupiata*.

Remarks. This population represents a 300 m increase in the maximum elevation known for this species to 4,660 m a.s.l., the highest record of any *Gastrotheca* species. In March 2018, more than 20 tadpoles were encountered. The following year, in May 2019, seven adult frogs were found and one was collected. The frogs were found on the northern side of Osjollo Pass in rocky puna (grassland) habitat situated above a series of tarns and bofedales (peatlands), fed by precipitation and glacial meltwater. Vegetation at the site is composed of a mixture of native cushion plants and grasses alongside non-native grasses introduced to feed cattle, which are present in low numbers at the site. The tadpoles were found in a small stagnant pond. The presence of both tadpoles and adult frogs over two consecutive years suggests an established breeding population. The weather at the site is typical of the high Andes, with rapid temperature swings and inclement weather such as hard frosts, snow, hail, and rain, including during the season when the frogs were observed. Temperature loggers at a site 2.5 km southwards into Osjollo Pass recorded an annual terrestrial high of 25 °C and low of −4.5 °C, and an annual aquatic high of 27.5 °C and low of −3 °C.

Discussion

We present new records for *Gastrotheca marsupiata* at 4,660 m a.s.l. in the Cordillera Vilcanota. This represents a 300 m vertical elevational extension of their known range, making *Gastrotheca marsupiata* the highest occurring species in its genus. Previous regular amphibian surveys of the Vilcanota that have been conducted since 2003 did not find *G. marsupiata* on transects along Osjollo Pass from 4,860–6,100 m a.s.l. However, these surveys did not include the site where this species was found (T. Seimon pers. comm. 7 July 2020; K. Reider pers. comm. 19 July 2020), so we cannot know how long

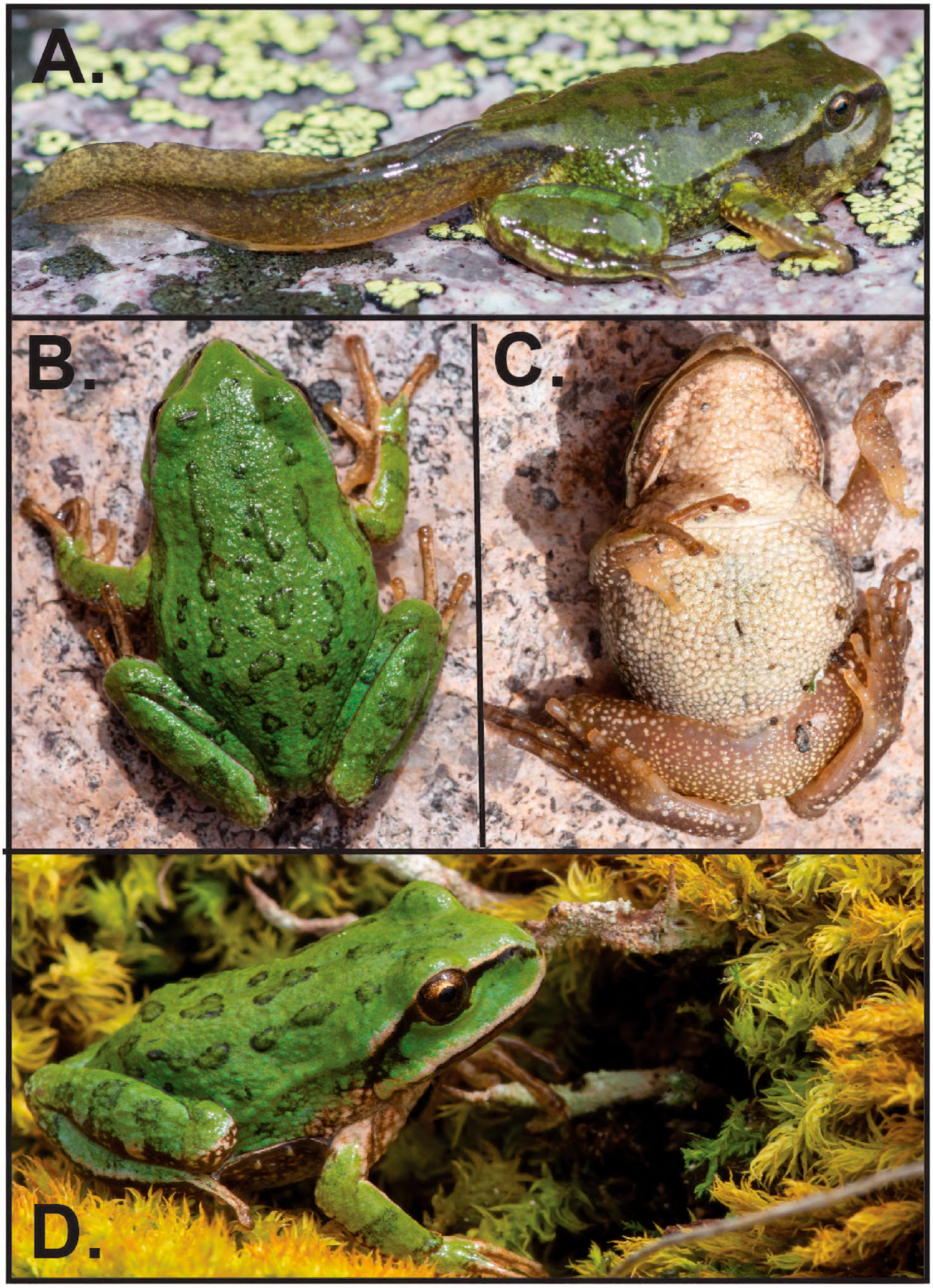

Figure 2. Tadpole and voucher individual of *Gastrotheca marsupiata*. **A.** Tadpole. **B–D.** Voucher individual: (**B**) dorsal, (**C**) ventral, and (**D**) lateral views.

G. marsupiata has occupied this habitat. Additionally, unlike the habitat recently colonized by *Telmatobius marmoratus*, *Pleurodema marmoratum*, and *Rhinella spinulosa* at the southern end and core of Osjollo Pass (Seimon et al. 2007), this site was not glaciated in 1931 aerial photographs (Shippee–Johnson Collection, Department of Library Services, American Museum Natural History; date inferred from Shippee 1933) and was probably not glaciated during the Little Ice Age maximum (1850–1900) given abundant lichen cover on nearby rocks. However, if this record does represent an upslope range extension into mountain pass habitat, it may be attributable to local changes in climatic conditions. Regardless, what *G. marsupiata* certainly has in common with these other local anuran species is that their occupancy of this extreme high elevation habitat will most likely be short-lived due to continued changing climatic conditions, as the supply of glacial meltwater feeding local streams and ponds ebbs.

The evidence for climate-driven range shifts in amphibians is still scarce. This is particularly true for poleward shifts, whereas limited evidence for climate-induced amphibian elevational range shifts has accumulated (Li et al. 2013). Over the last decades, amphibian elevational range shifts have been documented on the Tsaratanana Massif in Madagascar (Raxworthy et al. 2008), in Mount Gede Pangrango National Park in Indonesia (Kusrini et al. 2017), in the Ecuadorian Andes (Bustamante et al. 2005), in the Appalachian Mountains of the United States (Moskwik 2014), and in South Africa (Botts et al. 2015). In all of these cases, the authors suggest that the range shifts documented may have been driven by changes in the regional climate, and the authors of the Indonesian and Madagascan studies were able to rule out land use change entirely as a contributing factor since these studies were conducted within stably protected areas. Our new record for *G. marsupiata* represents a possible further case of contemporary climate-induced elevational range shifting, but we emphasize the critical role of extensive monitoring in being able to distinguish where, when, and how natural communities are truly changing over time.

Batrachochytrium dendrobatidis (Bd), the fungal pathogen that has caused declines and even extinctions of diverse amphibian species globally (Skerratt et al. 2007), has been detected from skin swabs of various Peruvian *Gastrotheca* species, including *G. excubitor* (Catenazzi et al. 2011), which is sympatric with *G. marsupiata* in portions of the Cordillera Vilcanota. However, a study examining the response of Andean frogs to Bd found that different *Gastrotheca* species have vastly different reactions and survival rates (Catenazzi et al. 2017), so it is difficult to predict whether *G. maruspiata* is susceptible prior to trial infection experiments. Although Bd has not yet been recorded in *G. marsupiata*, the species has experienced declines in neighboring Bolivia, even vanishing from parts of its former range (De La Riva and Reichle 2014). As the other amphibian species co-inhabiting Osjollo Pass have tested positive for Bd (Seimon et al. 2017), the susceptibility of *G. marsupiata* to Bd is another factor that may determine how long this species will persist in these extreme reaches of its elevational range.

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Authors' Contributions

ES, AS, FPC, YJG, and GC conducted biological fieldwork. GC translated Quechua. JCC assisted with permit acquisition and species deposition in the Museo de Biodiversidad del Perú. ES and AS wrote and FPC, YJG, and JCC edited the manuscript.

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